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1 NETWORK COOLED COATED WALL

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3 BACKGROUND OF THE INVENTION

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5 [0001] The present invention relates generally to gas turbine engines, and, more specifically,
6 to component cooling therein.

7 [0002] In a gas turbine engine, air is pressurized in a compressor and mixed with fuel for
8 generating hot combustion gases in a combustor. Energy is extracted from the combustion
9 gases in a high pressure turbine for powering the compressor, and additional energy is
10 extracted in a low pressure turbine which powers a fan in a turbofan aircraft engine
11 application, or drives an output shaft for marine and industrial applications.

12 [0003] Engine efficiency may be maximized by maximizing the temperature of the
13 combustion gases from which energy is extracted. However, the combustion gases must be
14 contained in the engine by various components which are therefore subject to heating
15 therefrom.

16 [0004] Typical components exposed to the hot combustion gases include the liners of the
17 combustor, the vanes and bands of turbine nozzles, and rotor blades and their surrounding
18 turbine shrouds, for example. These hot components are typically made of state-of-the-art
19 high strength superalloy materials, typically nickel or cobalt based for gas turbine engine
20 applications. These superalloys are expensive, but maximize the high temperature strength of
21 the hot components for achieving the desired long useful life thereof for reducing maintenance
22 operations and corresponding costs.

23 [0005] In conjunction with the superalloy composition of these hot engine components,
24 cooling air bled from the compressor is also used for providing cooling during operation.
25 Various configurations of cooling apertures and channels are provided in these hot
26 components for suitably channeling the pressurized air coolant therethrough for providing
27 internal cooling. The spent cooling air is typically discharged from film cooling holes
28 extending through the inboard or exposed surfaces of the components directly facing the hot
29 combustion gases for providing a thermally insulating cooling air film layer between the
30 component and the hot combustion gases.

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1 [0006] These hot components may also be further protected by providing thereon thermal
2 barrier coatings (TBC) which are typically ceramic materials providing additional thermal
3 insulation between the metal substrates of the components and the hot combustion gases.

4 [0007] Thermal barrier coatings are typically applied to the metallic substrates atop a
5 metallic bond coat therebetween, although thermal barrier coatings without bond coats are
6 being developed. The bond coat provides a bonding interface layer for improving the bond of
7 the ceramic thermal barrier coating atop the substrate, and additionally provides oxidation
8 resistance.

9 [0008] The proper operation of the thermal barrier coating requires heat conduction through
10 the coating, through the bond coat, and through the metallic substrate into the cooling circuits
11 which extract heat therefrom. Not only does the metallic substrate have maximum
12 temperature operating limits, but the bond coat and thermal barrier coating also have their
13 respective maximum temperature limits which should not be exceeded for ensuring the
14 desired useful life thereof.

15 [0009] However, the performance of superalloy metallic substrates, and the various forms of
16 conventional thermal barrier coatings and their corresponding bond coats is nevertheless
17 limited by the ability of the air coolant to cool these materials for maintaining them below
18 their maximum operating temperatures. Although the spent cooling air is additionally used in
19 the cooling film for thermally insulating and protecting the thermal barrier coating itself, the
20 thermal barrier coating necessarily requires cooling itself which occurs through conduction to
21 the underlying bond coat and metallic substrate.

22 [0010] Accordingly, it is desired to provide improved cooling of the thermal barrier coating
23 itself when applied atop the metallic substrate.

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BRIEF DESCRIPTION OF THE INVENTION

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27 [0011] A turbine wall includes a metal substrate having front and back surfaces. A thermal
28 barrier coating is bonded atop the front surface. A network of flow channels is laminated
29 between the substrate and the coating for carrying an air coolant therebetween for cooling the
30 thermal barrier coating.

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BRIEF DESCRIPTION OF THE DRAWINGS

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4 [0012] The invention, in accordance with preferred and exemplary embodiments, together
5 with further objects and advantages thereof, is more particularly described in the following
6 detailed description taken in conjunction with the accompanying drawings in which:

7 [0013] Figure 1 is an axial sectional view of a portion of an exemplary gas turbine engine
8 including a turbine shroud surrounding a row of turbine rotor blades.

9 [0014] Figure 2 is an isometric view of the one of the turbine shrouds illustrated in Figure 1
10 in accordance with an exemplary embodiment.

11 [0015] Figure 3 is a plan view of the front surface of the shroud illustrated in Figure 2 and
12 taken generally along line 3-3.

13 [0016] Figure 4 is a radial sectional view through a portion of the shroud illustrated in
14 Figure 3 and taken along jog line 4-4, extending in part along a row of aperture outlets.

15 [0017] Figure 5 is a radial sectional view, like Figure 4, of the turbine shroud in accordance
16 with another embodiment.

17 [0018] Figure 6 is a front plan view of the turbine shroud, like Figure 3, in accordance with
18 another embodiment.

19 [0019] Figure 7 is a front plan view of the turbine shroud, like Figure 3, in accordance with
20 another embodiment.

21 [0020] Figure 8 is an axial sectional view of the turbine shroud illustrated in Figure 2 in
22 accordance with another embodiment.

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DETAILED DESCRIPTION OF THE INVENTION

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26 [0021] Illustrated in Figure 1 is a portion of a gas turbine engine 10 which is axisymmetrical
27 about a longitudinal or axial centerline axis 12. The engine includes a multistage axial
28 compressor 14 that pressurizes air 16 which is suitably channeled to an annular combustor 18,
29 shown in aft part.

30 [0022] The air is mixed with fuel in the combustor and ignited for generating hot

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1 combustion gases 20 which are discharged therefrom between the stator vanes 22 of a high
2 pressure turbine nozzle. The vanes guide the combustion gases through of row of high
3 pressure turbine rotor blades 24 which extend radially outwardly from a supporting rotor disk
4 that is joined in turn to the compressor for providing power thereto during operation.

5 [0023] Another turbine nozzle follows the first stage rotor blades 24 for further guiding the
6 combustion gases downstream to a low pressure turbine (not shown) which extracts further
7 energy for powering an upstream fan in a typical turbofan gas turbine engine application, or
8 the low pressure turbine may be joined to an output drive shaft in a marine or industrial
9 application.

10 [0024] As indicated above, the efficiency of the engine is related to the temperature of the
11 combustion gases 20, yet high temperature of the combustion gases requires suitable
12 protection of the various components subject to heating therefrom during operation. The
13 combustor itself includes outer and inner liners which bound the combustion gases as they are
14 formed, and the turbine nozzles include vanes and outer and inner bands along which the
15 combustion gases flow.

16 [0025] The turbine rotor blades 24 are bathed in the hot combustion gases during operation,
17 and are surrounded by a segmented turbine shroud 26 which bounds the combustion gases.

18 [0026] These various components are typically made from various forms of superalloy
19 metals, typically nickel or cobalt based for modern gas turbine engines. These hot
20 components are typically hollow and provided with suitable cooling circuits therein that
21 receive the pressurized air 16 from the compressor which is used as a coolant in reducing their
22 temperatures during operation.

23 [0027] These hot components may also be covered with suitable thermal barrier coatings for
24 providing additional thermal insulation between their metallic substrate and the hot
25 combustion gases which flow thereover during operation. As indicated above, it is desired to
26 provide cooling of the thermal barrier coatings themselves for enhancing the performance
27 thereof for protecting the metallic substrates from the hot combustion gases.

28 [0028] An exemplary turbine component of the engine illustrated in Figure 1 is the turbine
29 shroud 26 which is illustrated in more detail in Figure 2. The turbine shroud itself is arcuate in
30 the circumferential direction, with a full complement of such turbine shrouds 26 being joined

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1 end to end to surround the full row of rotor blades. The shroud includes an arcuate substrate
2 wall 28, which is typically formed of a suitable superalloy metal, such as nickel-based or
3 cobalt-based superalloys.

4 **[0029]** The shroud wall 28 has a first or front surface 30 which faces or is exposed to the hot
5 combustion gases during operation. The shroud also includes an opposite second or back
6 surface 32 facing outwardly away from the combustion gases and over which the air coolant
7 16 is suitably channeled during operation. Typically, the coolant is impinged normally against
8 the shroud back surface 32 for maximizing the cooling effect thereof.

9 **[0030]** In the exemplary shroud configuration illustrated in Figure 2, the substrate wall 28
10 itself is relatively thin, about 2.5 mm for example, and further includes forward and aft hooks
11 34,36 extending radially outwardly from the shroud back surface 32. The hooks are suitably
12 mounted in a hanger for supporting the row of turbine shrouds from an annular casing radially
13 above the row of rotor blades 24 in a conventional configuration.

14 **[0031]** As shown in Figures 2 and 3, the front surface 30 of the shroud is entirely covered
15 with a thermal barrier coating (TBC) 38 suitably affixed or bonded thereto. The thermal
16 barrier coating is preferably a ceramic material of any conventional composition such as yttria
17 stabilized zirconia which provides enhanced thermal insulation for the shroud. Figure 4
18 additionally illustrates a transverse section through the turbine shroud of Figure 3 in which the
19 thermal barrier coating 38 is affixed to the front of the substrate wall 28.

20 **[0032]** Directly cooperating with the thermal barrier coating is a network or pattern of
21 cooling flow channels 40 laminated or disposed in a common layer between the substrate wall
22 28 and the thermal barrier coating 38 itself.

23 **[0033]** As shown in Figures 2 and 3, the substrate wall further includes a plurality of
24 aperture inlets 42 extending transversely or radially therethrough beginning from the back
25 surface 32. And, a plurality or row of aperture outlets 44 extends transversely or radially
26 through the thermal barrier coating 38. The inlets 42 and outlets 44 are disposed in flow
27 communication with the network of flow channels 40 for delivering the air coolant 16 thereto
28 and discharging the coolant therefrom.

29 **[0034]** In this way, the coolant 16 is first used for impingement cooling the back surface 32
30 of the turbine shroud illustrated in Figure 2 and then enters the inlets 42 for flow through the

1 network of flow channels 40 for then cooling the thermal barrier coating itself prior to
2 discharge from the row of outlets 44.

3 [0035] As shown in Figures 3 and 4 the flow channels 40 extend parallel between the
4 substrate wall and the coating 38 for cooling the interface therebetween. The inlets 42 and
5 outlets 44 extend transversely or radially through the wall and coating, respectively. Although
6 the transverse inlets and outlets provide local cooling in the immediate vicinity of the each
7 aperture, they alone lack the ability to uniformly cool the interface between the substrate and
8 the thermal barrier coating, provided instead by the network of flow channels.

9 [0036] As shown in Figure 4, the turbine shrouds preferably include a metallic bond coat or
10 layer 46 which is laminated between the substrate 28 and the thermal barrier coating 38 atop
11 or over the network of flow channels 40. As indicated above, bond coats are conventional for
12 providing a metallic bonding interface layer between the metallic substrate and the ceramic
13 thermal barrier coating. They also provide oxidation resistance for the substrate.

14 [0037] Conventional bond coats include diffusion PtAl or an overlay of MCrAlX in the
15 exemplary form of NiCrAlY or NiCoCrAlY, for example. Typical bond coats are applied
16 relatively thin, on the order of a few mils, relative to the substantially thicker barrier coating.

17 [0038] In the preferred embodiment illustrated in Figures 3 and 4, the flow channels 40 are
18 disposed directly in the substrate wall 28 by being suitably cast or machined therein. In this
19 way, the network of channels 40 is formed in the shroud front surface 30 directly below the
20 bond coat 46 which is suitably applied in a uniform and thin layer of a few mils over the entire
21 front surface including the flow channels therein. In turn, a relatively thick and uniform
22 thermal barrier coating 28 is suitably applied atop the bond coat 46 for completing the thermal
23 barrier coating of the shroud.

24 [0039] In this way, the inlets 42 are sized for metering and controlling the flowrate of the
25 inlet coolant to the flow channels 40. The coolant flows through the flow channels for directly
26 cooling the interface between the thermal barrier coating and the substrate wall. Furthermore,
27 the coolant in the flow channels provides additional thermal insulation for the metallic
28 substrate itself and therefore provides yet additional thermal insulation from the hot
29 combustion gases, in addition to the thermal insulation provided by the thermal barrier coating
30 and the film cooling air flowing thereover.

1 [0040] It is also noted that the flow channels are located directly below the bond coat 46 and
2 therefore additionally cool the bond coat which improves the ability of the bond coat to retain
3 and support the thermal barrier coating thereatop.

4 [0041] Figure 5 illustrates an alternate embodiment of the flow channels 40 disposed
5 between the substrate wall 28 and the thermal barrier coating 38. In this embodiment, the
6 flow channels 40 are disposed in the bond coat 46 itself below the thermal barrier coating 38
7 and atop or over the substrate 28. In this embodiment, the bond coat 46 is substantially thicker
8 than the conventional bond coat illustrated in Figure 4 in order to provide sufficient space for
9 introducing the flow channels 40 directly in the bond coat.

10 [0042] The dimensions of the flow channels 40 in either embodiment of Figure 4 and 5 may
11 range from about 15 mils or 0.38 mm to about 60 mils or about 1.5 mm in square or
12 rectangular profiles having generally U-shapes. The size of the flow channels should be small
13 enough to fit within the relatively thin substrate wall, or within the bond coat. And, the flow
14 channels should be large enough to minimize dust accumulation therein during operation for
15 preventing their premature clogging over extended life in dusty operating environments.

16 [0043] Since the bond coat itself is metallic it provides inherent strength for covering the
17 hollow flow channels, while additionally providing a continuous surface upon which the
18 thermal barrier coating may be bonded. The metallic bond coat therefore seals the network of
19 flow channels for preventing leakage of the cooling air therefrom into the ceramic thermal
20 barrier coating, with the cooling air from the flow channels being discharged solely through
21 the outlets 44 specifically provided therefor.

22 [0044] The network of flow channels 40 may have any suitable configuration and surface
23 area as desired for suitably cooling the thermal barrier coating on the intended turbine
24 components. For the exemplary turbine shroud components illustrated in Figure 3, the
25 network of flow channels includes those dedicated as inlet and outlet headers 48,50, with the
26 remaining flow channels 40 defining cross channels extending between the headers for
27 carrying cooling flow therebetween in parallel.

28 [0045] For example, in the embodiment illustrated in Figure 3 the cross channels 40 extend
29 transversely between the inlet and outlet headers 48,50. The cross channels 40 are preferably
30 straight and extend directly from the inlet header 48 directly to the outlet header 50, and all

1 operate in unison or parallel flow for channeling the coolant axially along the turbine shroud
2 from its trailing edge at the aft hook to the leading edge at the forward hook.

3 **[0046]** Figure 6 illustrates a modification of the Figure 3 embodiment in which the cross
4 channels 40 are arranged in multiple serpentine legs axially between the inlet and outlet
5 headers 48,50. In the exemplary configuration illustrated, the cross channels define a
6 five-pass serpentine channel at both circumferential ends of the turbine shroud, and then
7 corresponding three-pass serpentine channels inboard therefrom, with a single flow channel
8 disposed symmetrically therebetween and extending directly between the inlet and outlet
9 headers.

10 **[0047]** In the embodiments illustrated in Figures 3 and 6, the flow channels extend generally
11 parallel to each other along the axial direction of the turbine shroud and generally transverse
12 or perpendicular to the circumferentially extending headers 48,50.

13 **[0048]** Figure 7 illustrates yet another alternate embodiment in which the cross channels 40
14 extend primarily parallel with the inlet and outlet headers 48,50 along the circumferential
15 direction of the turbine shroud. Yet again, the cross channels 40 in this embodiment may be
16 arranged in multiple serpentine legs between the two headers, with two three-pass serpentine
17 configurations being illustrated for example.

18 **[0049]** In the several embodiments illustrated in Figures 3, 6, and 7, the inlet header 48 and
19 the inlets 42 therein are disposed adjacent the aft hook 36 shown in Figure 2, with the outlet
20 header 50 and the outlets 44 being disposed at the opposite, forward end of the shroud
21 adjacent the forward hook 34. In this way, the spent impingement air is first used to cool the
22 back surface 32 of the turbine shroud illustrated in Figure 2 and then flows through the row of
23 inlets 42 adjacent the aft hook 36.

24 **[0050]** The coolant then flows through the flow channels forwardly inside the turbine shroud
25 for discharge from the row of outlets 44 located below the forward hook 34 through the
26 thermal barrier coating. In this way, the discharged coolant then flows downstream over the
27 thermal barrier coating to provide a thermally insulating film or layer of air for further
28 protection thereof from the hot combustion gases.

29 **[0051]** Illustrated in Figure 8 is yet another embodiment of the turbine shroud which may
30 include the various configurations of the network of channels 40 illustrated in Figures 3-7, but

1 modified for reversing the direction of coolant flow. In this embodiment, the inlet header 48
2 and the inlets 42 are disposed adjacent to the forward hook 34 of the shroud, and the outlet
3 header 50 and outlets 44 are disposed at the opposite aft end of the shroud adjacent the aft
4 hook 36.

5 [0052] The coolant 16 therefore flows from the upstream, forward end of the turbine shroud
6 through the flow channels between the substrate wall and the thermal barrier coating, and is
7 discharged at the aft end of the turbine shroud. In this embodiment, an additional row of
8 conventional film cooling holes 52 may be provided through the base of the forward hook 34
9 for channeling another portion of the coolant 16 from the back surface 32 of the turbine
10 shroud for discharge through the thermal barrier coating along the forward or leading edge of
11 the turbine shroud. The air discharged from the film cooling holes 52 may then be used for
12 establishing the thermally insulating film of cooling air extending aft or downstream over the
13 thermal barrier coating.

14 [0053] Figure 4 illustrates in flowchart form an exemplary method of making the cooled
15 turbine shroud having the flow channels formed in the metal substrate. More specifically, the
16 metallic portion of the turbine shroud may be formed in any conventional manner such as
17 casting or machining, with the network of flow channels 40 being suitably formed by casting
18 or machining in the front surface 30 of the substrate wall 28.

19 [0054] The network of flow channels 40 is then suitably masked by filling the flow channels
20 with a suitable masking material 54 which can withstand the high temperature process in
21 which the bond coat and thermal barrier coating are applied. A suitable mask 54 may include
22 various compounds such as NaCl, MgO, TiO₂, Al₂O₃, or Y₂O₃ for example.

23 [0055] The bond coat 46 may then be applied in a conventional manner such as high
24 temperature spraying over the substrate front surface 30 and over the masked channels 40
25 filled flush with the masking compound 54. Next, the thermal barrier coating 38 may then be
26 applied in any conventional manner such as high temperature spraying over the previously
27 applied bond coat 46. The thermal barrier coating is typically thicker than the bond coat and
28 may have any suitable thicknesses as desired.

29 [0056] The mask 54 may then be suitably removed from the flow channels 40 by leaching or
30 washing away thereof using a suitable caustic solvent, such as KOH. Since the inlet apertures

1 42 may be preformed or predrilled in the turbine shroud prior to the application of the bond
2 coat and thermal barrier coating and mask, those apertures may be used for removing the
3 mask after the shroud is coated.

4 [0057] The outlet apertures 44 may be suitably drilled by laser or electrical discharge
5 machining (EDM), for example, through the thermal barrier coating and bond coat to reach
6 the outlet header 50 for establishing flow communication therewith. If desired, the mask
7 removal may be conducted after the outlet apertures 44 are formed for improving the ability to
8 flush or leach the masking compounds completely from the now hidden flow channels 40.

9 [0058] Figure 5 illustrates a modification of the method of making the turbine shroud in
10 which the metallic shroud itself is conventionally formed without the flow channels therein.
11 In this embodiment, the substrate front surface is masked at a plurality of locations
12 corresponding with the intended network of flow channels 40. The mask 54 may have a
13 suitably viscous or putty-like consistency, and may be applied in the form of tapes for
14 achieving the desired shape and size for the subsequent flow channels.

15 [0059] The bond coat 46 may then be conventionally applied over the front surface 30 of the
16 substrate as well as over the masked locations. The bond layer is typically applied in layers to
17 fill the spaces between the masked locations and then completely cover the network of
18 masked locations to a suitable thickness, which is substantially thicker than conventionally
19 applied bond coats.

20 [0060] The thermal barrier coating 38 may then be conventionally applied over the
21 previously applied bond coat 46 in suitable thickness atop the bond coat.

22 [0061] The mask 54 is then suitably removed by leaching or flushing from within the bond
23 coat 46 for leaving therebehind the open flow channels 40 therein. As indicated above, the
24 inlet apertures 42 may be preformed in the substrate wall 28 for permitting removal of the
25 mask later in the process.

26 [0062] The outlet apertures 44 may then be suitably drilled through the thermal barrier
27 coating and bond coat for establishing flow communication with the outlet header 50.

28 [0063] In Figure 5, the network of flow channels 40 is formed solely within the metallic
29 bond coat 46 and provides direct cooling thereof, and cooling of the interface region between
30 the thermal barrier coating 38 and the metallic substrate 28.

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1 [0064] In the Figure 4 embodiment, the flow channels 40 are formed in the front surface 30
2 of the metallic substrate 28 and therefore cool the thin bond coat 46 and thermal barrier
3 coating 38 in turn therefrom.

4 [0065] In both embodiments illustrated in Figures 4 and 5, the coolant air is better used for
5 cooling the bond coat and the thermal barrier coating for improving their thermal insulation
6 performance and introducing yet another mechanism for cooling thereof independent of the
7 conduction cooling of the coating and bond coat inwardly through the metallic substrate 28.

8 [0066] The so cooled thermal barrier coating in the various embodiments disclosed above
9 can significantly lower the temperature thereof as well as the temperature of the bond coat,
10 and therefore improves the thermally insulating performance of the coating while improving
11 the life thereof.

12 [0067] While there have been described herein what are considered to be preferred and
13 exemplary embodiments of the present invention, other modifications of the invention shall be
14 apparent to those skilled in the art from the teachings herein, and it is, therefore, desired to be
15 secured in the appended claims all such modifications as fall within the true spirit and scope of
16 the invention.

17 [0068] Accordingly, what is desired to be secured by Letters Patent of the United States is
18 the invention as defined and differentiated in the following claims in which we claim: